Methods for Shape Estimation of Small Body

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INTRODUCTION The exploration of space resources will be a part of major space developments in the 21st century. Among the extraterrestrial bodies in the solar system, minor bodies, particularly asteroids, are very attractive targets, not only because of their scientific value but also because they are promising extraterrestrial resources for future exploitation. Recently, the growing international interest in these small bodies has resulted in many spacecraft exploration plans being proposed, and some of these are now in action. We have also proposed a mission concept for Phobos/Deimos exploration[1].

In small body explorations, precise measurement of size, shape and mass is one of the most important tasks, but is also challenging as it is usually quite difficult to obtain much information about these physical characteristics. In particular, the gross density of a target body is a very important index for the estimation of composition, since layer formations of composite material are not expected in bodies of such small size. If we can obtain the mass of the target from observation of the perturbed motion of the spacecraft near the target, we can determine the gross density using the target's volume. In order to determine the volume, we must know the target's precise shape.

We have attempted to apply some schemes originally developed for Earth remote-sensing data processing to the estimation of a small body's shape. In this paper we describe some preliminary results, which consist of three parts: (1) Parallel matching experiment of control points between different images of the target body by computer simulation using large scale parallel processors; (2) Application of an automatic shape recognition scheme to celestial shape estimation; (3) Application of a massively-parallel processing scheme to crater recognition.

PRELIMINARY RESULT (1): Matching Method for Small Body Shape Estimation

In estimating the shapes of small bodies, a key technology is to find automatically conjugate points on craters in plural images taken from different positions. We have developed an effective solution to this problem [2]. The algorithm of forming a triangle-side-list using three conjugate craters can automatically determine the exact conjugate points between two different images.

Applying this method to plural overlapped images, relative shapes on the overlapped surface are estimated. Suppose that for two images, x=(x,y,z) and x'=(x',y',z') , the x and x' are related by Equation 1 in a coordinate system with its origin at the center of the camera's view:

$$x' = Rx + t \qquad \text{(Eq.1)}$$

where R is a rotation matrix about the origin and t a parallel transition vector.

Based on more than 8 pairs of conjugate points which are determined automatically using the triangle-side-list of craters extracted by automatic recognition [3], the shape of the small body can be determined from Equation 1.

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PRELIMINARY RESULT (2): Automatic Recognition of Small Body Shapes

Automatic recognition of shapes of arbitrary size, such as craters, has been a subject of study. In order to recognize the shape information precisely and to extract it accurately from remotely-sensed images, we have devised an effective scheme with load reduction for automatic shape recognition for space remote-sensing [3].

The mapping algorithm, which was developed as a robust recognition scheme, can be extended to recognize arbitrary shapes whose equations are in the form:

$$f(x, y, a_1, a_2, ..., a_p) = 0 \qquad \text{(Eq.2)}$$

where x,y are position variables in the image space and the a_i (i=1, p) are parameters which define the shape.

This proposed shape recognition scheme drastically reduces the memory volume required for the extraction of shape structures, and this reduction becomes more marked when recognizing more complicated shapes. The reduced computer load which is characteristic of this method will be useful for small architectures such as for on-board processing.

PRELIMINARY RESULT (3): Massively-Parallel Processing for Crater Recognition

In shape recognition in remotely-sensed images, complicated shapes make higher speed processing necessary. Advanced processing by a parallel architecture such as a massively-parallel computer is a promising method of achieving such speeds [4]. In our scheme, an optimally parallel criterion is based on the equalization of computational load between each of the node processors (NP). The number of divisions of the computational load is optimized according to the number of NPs. In this algorithm, we have used a scheme of massive parallel of memory area for the parameter space instead of image data parallel because of inevitability of detecting the maximum histogram in the parameter space.

This massively-parallel scheme with optimum division of the computational load can execute shape recognition effectively and can address the problem of high-speed processing. It might possibly be applied to on-board processing architectures.

REFERENCES

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